



# ADDITIVE MANUFACTURING FOR SPACE IMAGING

MARVIN CALDERON, ARDEN GAO, ETHAN SANNA, JAKE SNYDER  
 UNIVERSITY OF ROCHESTER, HAJIM SCHOOL OF ENGINEERING AND APPLIED SCIENCES  
 DEPARTMENT OF MECHANICAL ENGINEERING



## Problem Statement

Metal additive manufacturing has become relevant in the aerospace industry as an efficient and economical means of manufacturing. As such, L3Harris has tasked the group with the designing, 3D printing, and testing Forward Metering Structure (FMS) for an optical satellite for rapid deployment.

## Requirements and Specifications

Requirement ID	Description
[UR-FMS-001]	Quasi-static launch loads of 30 g spherical sweep, swept at 15-degree increments, while supporting all hosted hardware.
[UR-FMS-002]	Factors of Safety (FOS) <ul style="list-style-type: none"> <li>Yield <math>\geq 2.0</math></li> <li>Ultimate <math>\geq 2.5</math></li> <li>Ultimate Glass <math>\geq 5</math></li> <li>Buckling <math>\geq 2.5</math></li> </ul>
[UR-FMS-003]	Under a 1°C isothermal temperature change, the average motion of the SM interface shall be limited to: <ul style="list-style-type: none"> <li>0.2 <math>\mu\text{m}</math> (7.87 micro inches) translation (RSS of X and Y), and</li> <li>0.9 <math>\mu\text{rad}</math> rotation (RSS of Rx and Ry)</li> </ul>
[UR-FMS-006]	Mass < 25 <b>lbm</b>
[UR-FMS-007]	First Mode > 60 Hz
[UR-FMS-020]	Obscuration < 22 %

Table 1: Requirements

FMS Total Hosted Mass – Masses below are basic, must be multiplied by Mass Growth allowance denoted in UR-FMS-006

- SM: 4.1 **lbm**
- Shade Assy: ~4.5 **lbm** (use as-designed mass plus 2lb thermal electric hardware)
- FMS Thermal electric hardware (distributed across the entire structure): 1.25 **lbm**

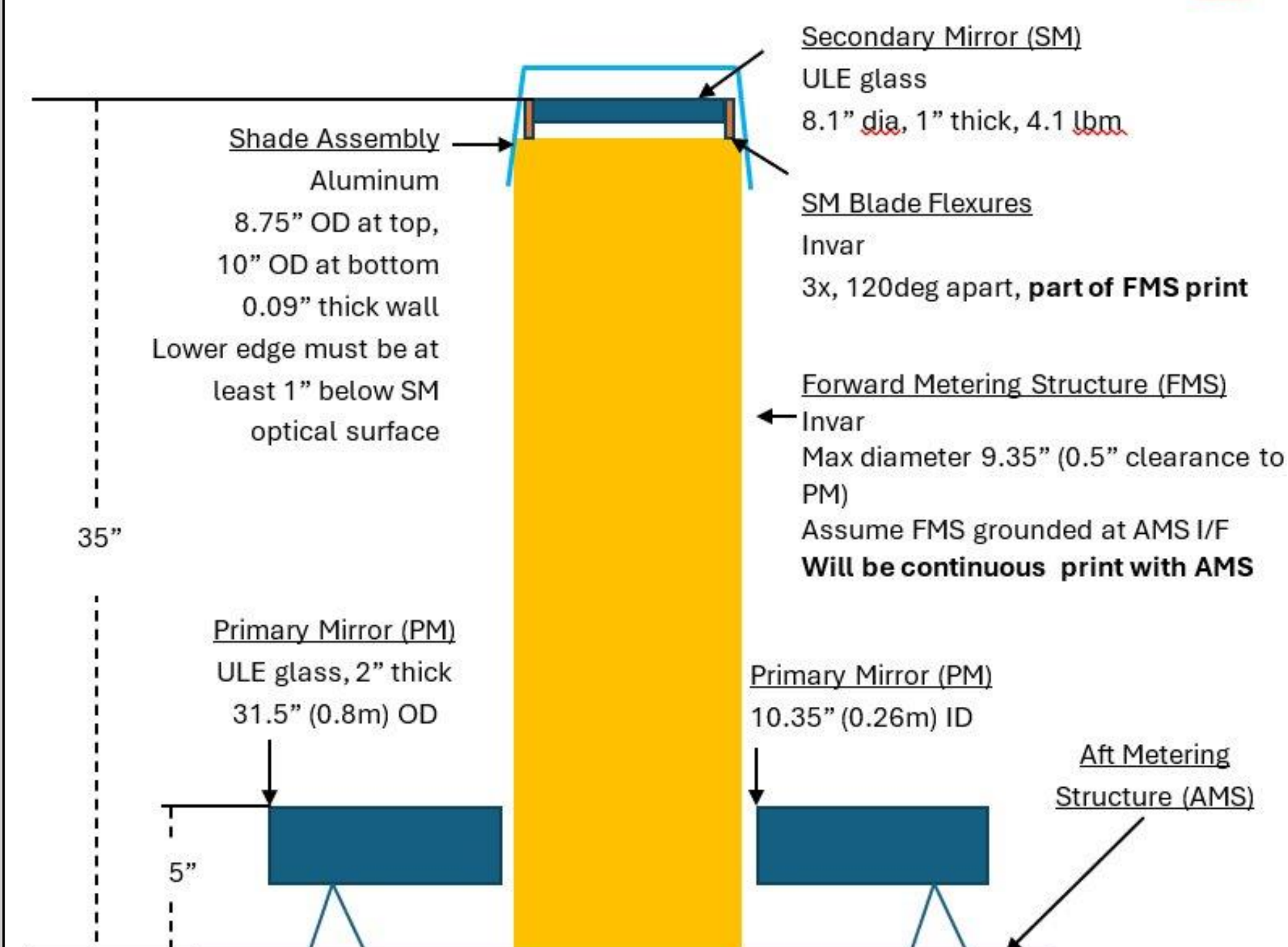
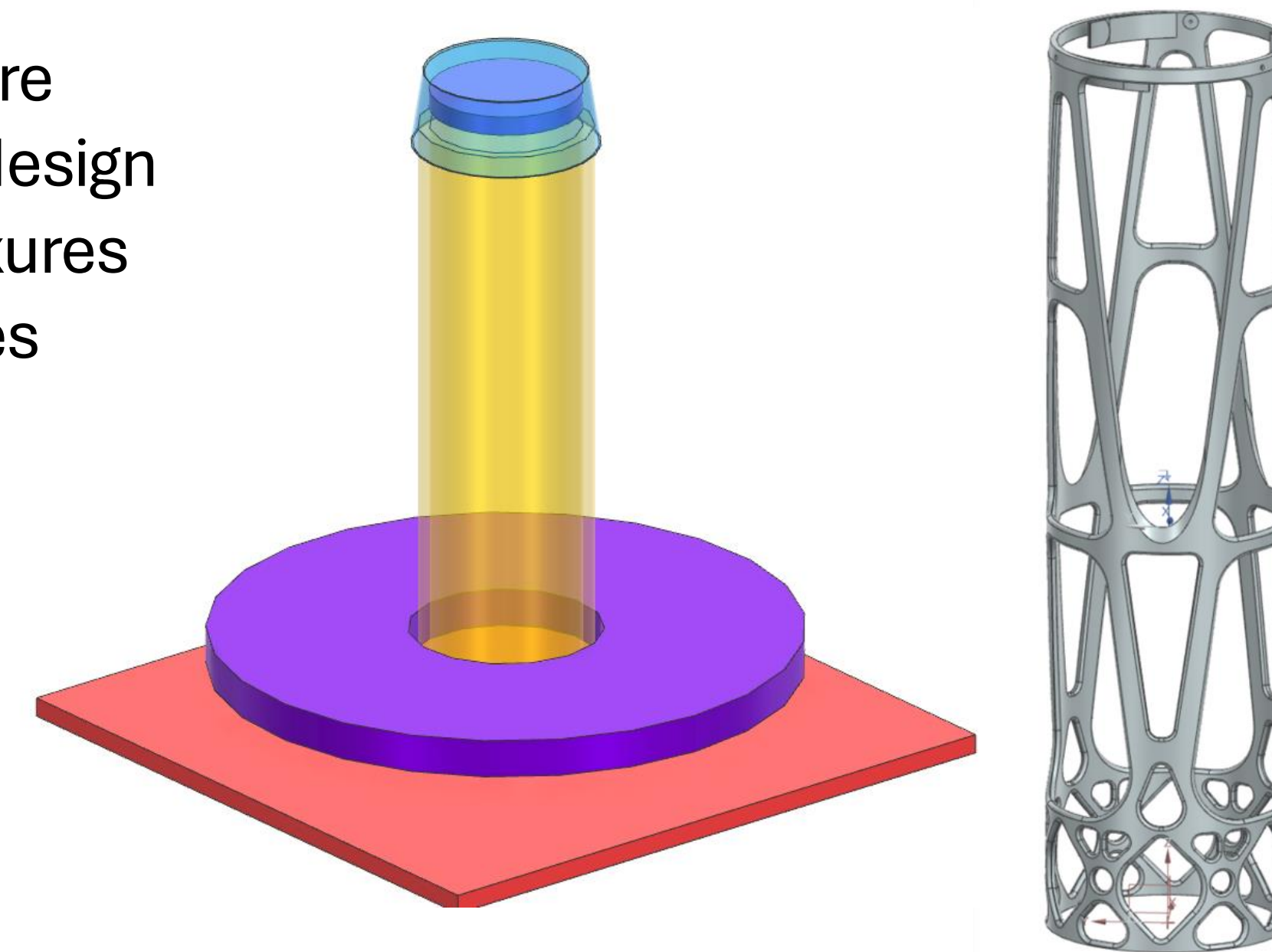


Figure 3: Mechanical Interface Control Drawing

## Concept Description

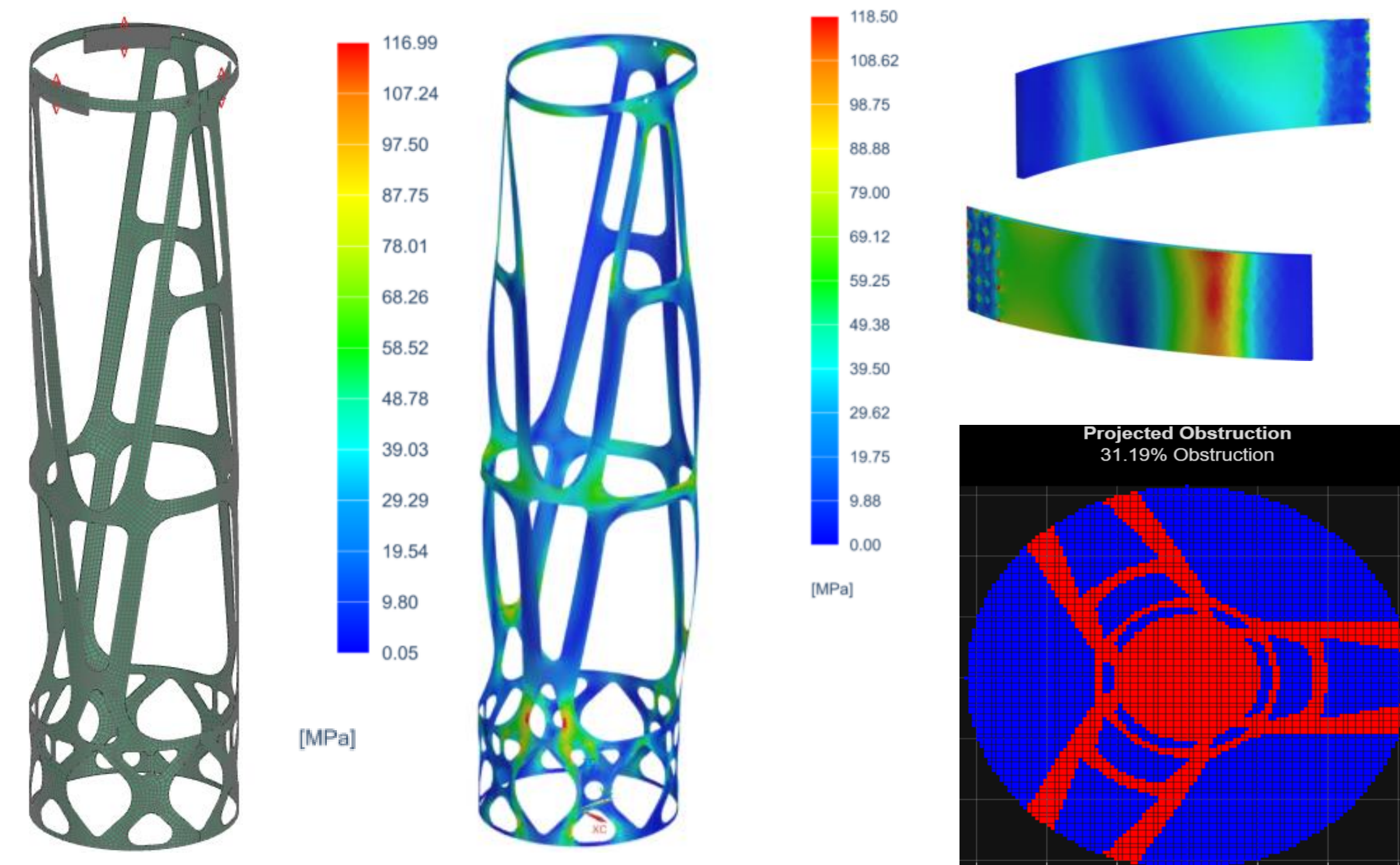
The design of the Forward Metering Structure was bounded a design envelope. The final design iteration To connect the FMS to the SM, flexures were created on the top ring. Threaded holes were also developed to attach the shade assembly to the FMS.

Figure 3 (Left): System design envelope. The design envelope of FMS is in yellow  
 Figure 4 (Right): Final FMS design



## Analysis

NASTRAN Finite Element Analysis was performed to test the model against mechanical specifications. A light ray package supplied by L3Harris was used in combination with MATLAB to determine obscuration.



Figures 5-8 (Left to right): 5: Final iteration Finite Element Model. 6: Spherical sweep simulation (worst-case stress results) showcase a passing yield stress on the body. 7: Spherical sweep simulation (worst-case stress results) showcase passing stress on flexures. 8: Obstruction simulation show a failing obscuration specification.

## Manufacturing

- Final Prototype produced was a Full-Scale 100%-Infill ABS print performed on a Stratasys F270 FDM Printer in Rettner Fabrication Studio.
- GrabCAD Print estimates were used to record print time, ABS material usage, and QSR support material usage for each section.
- While the ABS prototype was not equivalent to the intended DMLS Invar structure, the print-time and material data provided a realistic manufacturing estimate for the physical system delivered by the team.

Section	Print Time (hr:min)	ABS Material (l)	QSR Support Material (l)
1	10:01	9.345	4.273
2	09:49	10.143	4.046
3	07:25	5.54	3.828
4	18:07	16.238	5.506
5	16:01	16.498	3.466
6	17:41	16.028	7.366
<b>Subtotal</b>	<b>79:04</b>	<b>73.792</b>	<b>28.485</b>
Item	Cost		
ABS Material	\$786.85		
QSR Material	\$108.24 (estimated)		
<b>Total</b>	<b>\$895.09</b>		

Table 2: Print Data



Figure 9: Prototype

## Testing

To understand the true properties of Invar, material testing was performed on samples of solid invar and compared to simulated results. Additionally, a vibration test was performed to the first mode of the physical prototype to simulated values. With corrected simulation density, simulated value of 45.56 Hz and an experimental value 46.51 Hz were achieved, showcasing only a 2% error.

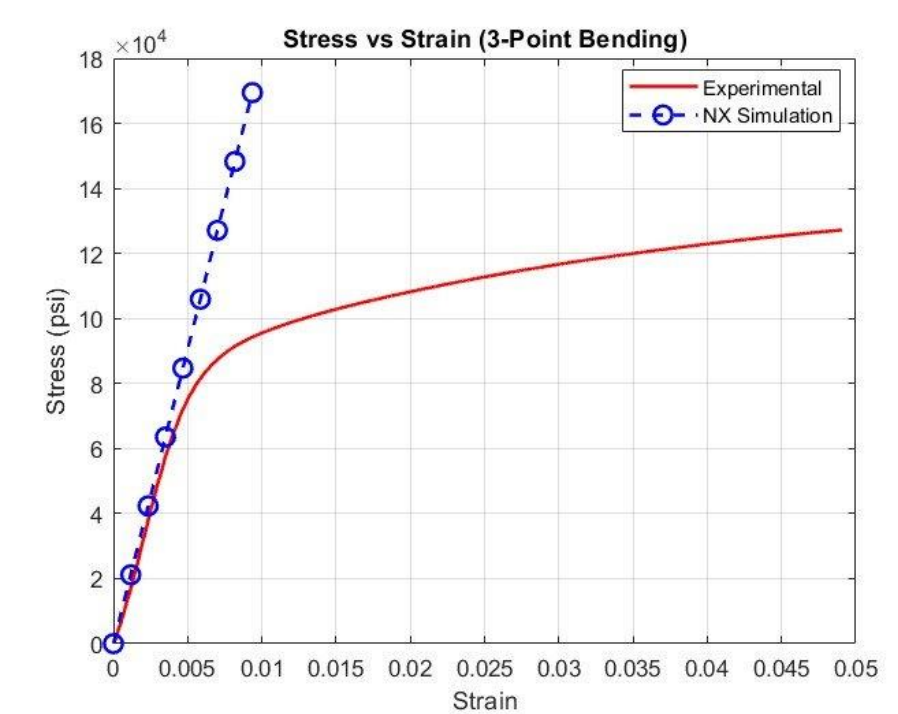


Figure 10: Tested Invar stress strain-curve

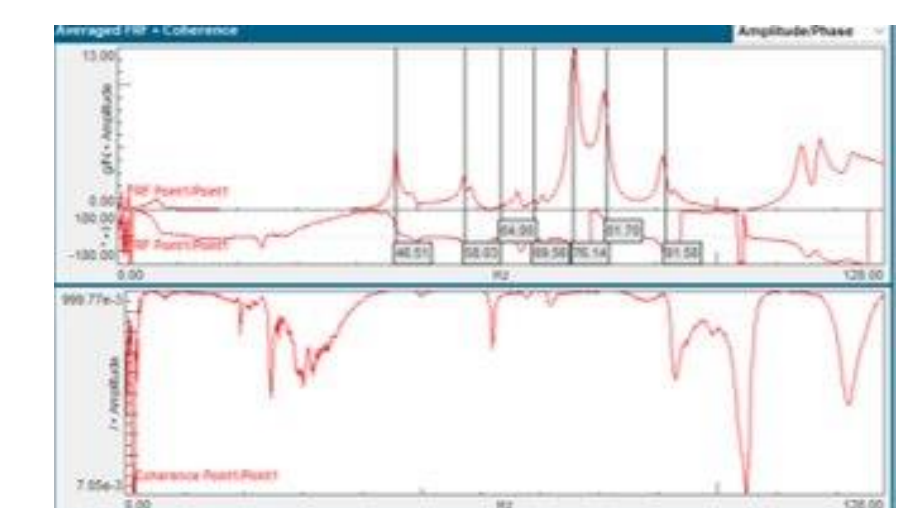


Figure 11: Vibrational Data

	Simulation with test density	Test 1	% Error
1 <sup>st</sup> Mode	45.56	46.51	2%

Table 3: Model Correlation

## Evaluation of Requirements and Specifications

CRITERIA	Design: 26c026607A
UR-FMS-001	Compliant
UR-FMS-002	Yield: 0.0127 > 0 Ultimate: 0.526 > 0 SM Ultimate: 0.390 > 0 Buckling: 7.23
UR-FMS-003	RSS: 7.10 $\mu\text{m}$ RSS: 0.0108 $\mu\text{rad}$
UR-FMS-006	24.63 <b>lbm</b>
UR-FMS-007	61.82 <b>Hz</b>
UR-FMS-020	31.19%

Legend  
 Expected Compliance  
 Not Compliant

## Future Work

With additional time and resources, the team would like to continue iterating the design to meet the final requirement and perform testing on a more representative sample such as a DMLS fabricated metal.

## Acknowledgements

We would like to thank Professor Muir, Patrick Ellsworth, Pat Zinter, Steve Sutton, Devin Woodyard, Jim Alkins, Chris Pratt, and Angel Bermudez for their guidance and support throughout this project.